

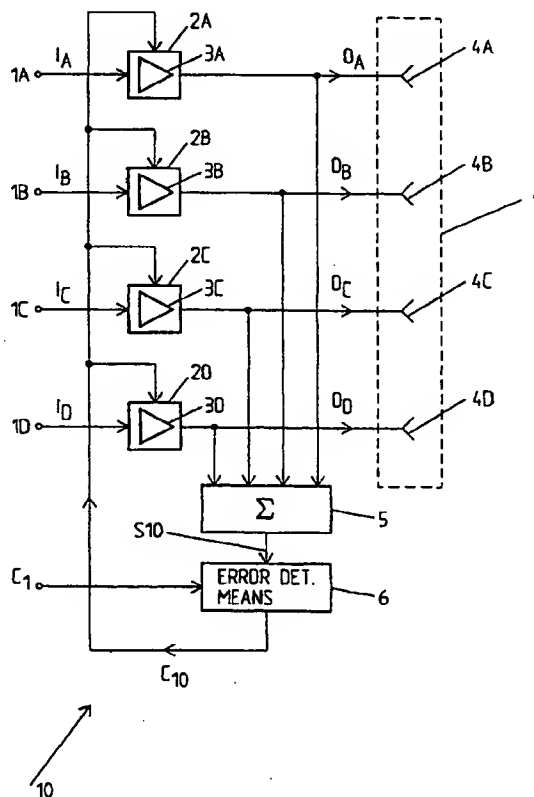


## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>6</sup>:</b> <b>H03F 3/21, H03G 3/20, H01Q 23/00</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 00/03479</b> <b>(43) International Publication Date:</b> 20 January 2000 (20.01.00)
<b>(21) International Application Number:</b> PCT/SE99/01163 <b>(22) International Filing Date:</b> 29 June 1999 (29.06.99) <b>(30) Priority Data:</b> 9802498-7      10 July 1998 (10.07.98)      SE <b>(71) Applicant:</b> TELEFONAKTIEBOLAGET LM ERICSSON (publ) [SE/SE]; S-126 25 Stockholm (SE). <b>(72) Inventors:</b> JOHANNISSON, Björn; Kaptensgatan 9, S-434 31 Kungsbacka (SE). LUBEREK, Jarek; Gregorianska gatan 51, S-415 09 Göteborg (SE). <b>(74) Agents:</b> BERGENTALL, Annika et al.; Cegumark AB, P.O. Box 53047, S-400 14 Göteborg (SE).		<b>(81) Designated States:</b> AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

**(54) Title:** ARRANGEMENT AND METHOD RELATING TO RADIO COMMUNICATION**(57) Abstract**

The present invention relates to a multi-carrier power amplifying arrangement (10) which comprises a number of amplifying means (2A, 2B, 2C, 2D) each of which includes a main amplifier (3A, 3B, 3C, 3D) and linearizing means. Furthermore it comprises signal adding means (5) for adding the adding output signals from the amplifying means in phase, error detecting means (6) for detecting the average phase error of the amplified signals and for providing a compensating control signal (C<sub>10</sub>). Said compensating control signal is provided to each amplifying means at least to compensate for the average phase error.



**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakhstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

Title:

ARRANGEMENT AND METHOD RELATING TO RADIO COMMUNICATION

5

#### FIELD OF THE INVENTION

The present invention relates to a multi-carrier power amplifying arrangement and to a method of controlling at least the average phase error of a multi-carrier power amplifying arrangement. The invention also relates to an array antenna with an amplifying arrangement. Particularly the invention relates to minimizing radiated power intensity for intermodulation products.

#### STATE OF THE ART

15 In cellular mobile communication systems the geographical coverage area of a mobile communication network is divided into cells. For each of these cells a stationary base station is arranged to communicate with a plurality of mobile stations. Each base station (BS) is connected to an antenna, or a set of antennas, covering  
20 the cell in which the BS is arranged. This means that a base station on the downlink transmits in such a manner that all mobile stations within the cell can receive the signal. Most of the transmitted information is, however, point-to-point information intended for one single mobile station only. Most of the RF power  
25 will thus be transmitted in directions in which no transceiver will receive it. If the base station could concentrate the transmitted power vertically as well as horizontally to the desired directions, using antennas with radiation patterns characterized through narrow antenna lobes, a higher efficiency  
30 could be achieved.

If the same kind of antennas are used for reception in the base station as well (on the uplink), a corresponding improvement of the reception sensitivity is obtained in the desired directions. This concentration of the output power and the reception  
5 sensitivity can be used for increasing the transmission range or for lowering the requirements on the transmitter in the base station as well as on the transmitter in the mobile station. Since the channel frequency reuse potentially can be increased with this technique, the total capacity of the mobile communication network  
10 can be enhanced. These and other advantages have in the last few years resulted in a growing interest in antenna arrays with narrow antenna beams.

It is well known in the art that all amplifiers distort an input  
15 signal. The distortion becomes greater as the power levels are increased. When the amplifier is exposed to multiple input signals, intermodulation (IM) products are introduced. These IM products must be kept low because they interfere with the system in general and with other users in particular.

20 Current cellular communication standards impose stringent limits on radiated power intensity for intermodulation products. The use of a central multi-carrier power amplifier (MCPA), as in current mobile communication cellular systems, suffers from a disadvantage  
25 in this respect since not only the desired signal, but also the intermodulation products will be amplified/enhanced. The consequence thereof, in combination with the power requirements on the single multi-carrier amplifier, will be that the single multi-carrier amplifier needs to employ rather sophisticated techniques  
30 to reach the desired limits on the carrier to intermodulation ratio (C/I-ratio).

Since the amount of linearisation that can be provided is technologically limited, a central amplifier has to use a significant amount of back-off to reach the desired levels of intermodulation. This leads to a decreased efficiency which in turn results in a low DC to RF conversion efficiency.

In the article "Application of Linearised Amplifiers in Adaptive Antennas" by Hongxi et al, published in the IEEE MTT-S 1995 International Topical Symposium on Technologies for Wireless applications, and in which the use of adaptive antenna arrays for future mobile communication systems is discussed, a linearisation technique called feed-forward technique is proposed as the most suitable approach for suppression of intermodulation in the base stations.

The feed-forward technique, which has been applied for linearisation of a central multi-carrier power amplifier (MCPA), basically consists of two independent steps. The first step is to extract the distortion introduced by the main amplifier by comparing the amplified signal with the input signal. This step is referred to as extracting an error signal. The second step is to amplify this error signal and inject it in anti-phase and time aligned at the output of the feed-forward amplifier to thereby cancel out the distortion.

The performance of the feed-forward technique is dependent on the ability to add rotated signal vectors correctly in anti-phase and equal amplitude. This process determines how well a distortion component can be extracted or suppressed. The ability to control these variables, i.e., gain and phase, are therefore of crucial

importance in feed-forward amplifier systems. Hence, phase and amplitude adapters are employed. These adapters for a given environment can be tuned to give a minimum of phase and amplitude error. However, due to, e.g., temperature drift, an imbalance may occur, resulting in insufficient intermodulation suppression. For this reason, the general feed forward linearisation method is normally combined with an adaptive phase/amplitude control.

There are two main methods of how to implement this. The first method uses the actual distortion caused by the main amplifier to control the settings of the gain and phase controls. This is possible since it equals the first step in the feed-forward process. In this case, the error signal content is minimized at the output. The second method uses a known distortion simulating signal which is injected in the amplifier path and minimized at the output, thereby also reducing the distortion introduced by the main amplifier. The term distortion shall be understood to mean any signals present in the output of a device which were not present at the input.

US-A-5 386 198 discloses an example of a method of the second type for controlling a feed-forward compensated power amplifier. A spread spectrum technique is used to cover a control signal(s) and injects a composite signal at a suitable point into the feed-forward amplifier system to reduce distortion. Control signals after remapping of the spread spectrum at the output of the system are correlated in a match filter correlator and the result is used to control, in either polar or Cartesian co-ordinates, the injection, in anti-phase, of the extracted distortion into the feed forward amplifier output.

It is a drawback that the requirements as to linearisation of each amplifying means are too high and difficult, if not impossible, to meet in order to reach an acceptable carrier to intermodulation ratio (C/I-ratio).

5

It is particularly disadvantageous that the average phase error may be high and particularly it is disadvantageous that, when the conditions change, for example as compared to a first situation in which for a given temperature, the used control circuitry is tuned to give a zero average phase and amplitude error, the average phase error will increase considerably as for example the temperature changes (even if temperature compensated circuits are used). The average phase error will also increase considerably for high antenna gains and the limits as to the maximum allowed intermodulation intensity may easily be exceeded. It is also substantially impossible to detect and remove a resulting average phase error using the hitherto known arrangements and methods.

#### SUMMARY OF THE INVENTION

What is needed is therefore an amplifying arrangement, particularly a multi-carrier arrangement, through which the radiated power intensity of intermodulation products can be kept low in a simple and efficient manner. Particularly an arrangement is needed in which the requirements as to linearization are low on the respective amplifying means forming the amplifying arrangement, particularly lower than in hitherto known arrangements. An arrangement is also needed through which the power of intermodulation products can be kept low irrespectively of whether the conditions change in relation to any initial conditions, or generally under varying conditions and for a high antenna gain etc. Particularly an arrangement is needed through

which at least the average phase error (and advantageously also the amplitude error) can be detected and controlled or compensated for.

5 Particularly an arrangement is needed which is flexible, uncomplicated and easy to fabricate. An array antenna with such an arrangement is also needed through which the abovementioned objects are achieved as well as a method of controlling an  
10 amplifying arrangement or more particularly an active array antenna.

Therefore a multi-carrier power amplifying arrangement is provided. It comprises a number of amplifying means each comprising signal input means, signal output means, a main  
15 amplifier and means for linearizing the amplifying means. Furthermore signal adding means are provided for adding the output signals from the amplifying means in phase. Error detecting means are provided for detecting the average phase error of the amplified sum signal and for providing a compensating control  
20 signal. The compensating control signal is provided to each amplifying means to compensate for the average phase error. In a particular embodiment a reference signal is provided to each amplifying means, which reference signal is used to detect the average phase error of the sum of the amplified signals in the  
25 error detecting means. Still more particularly the reference signal may consist of a pilot signal which is input to each of the amplifying means and to the error detecting means. The error detecting means consists of means for detecting the signal level of at least one component originating from the pilot signal and  
30 the result is used in providing the compensating control signal. In a particular embodiment an externally controlled signal is



provided to the error detecting means to provide the compensating control signal.

In a particular embodiment the linearizing means consist of a number of feed forward loops, one for each amplifying means. Of course also other linearizing means can be used. In for example US-A-5 051 704, US-A-5 323 119, US-A-5 116 634, US-A-5 148 117, US-A-5 148 117, US-A-4 560 945, all of which allow external biasing, linearizing techniques are disclosed all of which in principle can be used to linearize the individual amplifying means as disclosed in the present invention.

Feed-forward loops implemented for linearization of distributed MCPA's may decrease the non-linearities with, e.g., 30dB. The remaining non-linear terms will have a random phase and amplitude. For any given temperature, the control circuitry can initially be tuned to yield zero average phase and amplitude error. Adaptive control circuits can be used to suppress temperature drift, but since there is a lowest detectable amplitude for the detection circuits in adaptive control circuits and since these circuits themselves are impaired with a temperature dependence, the average error may deviate from zero. This non-zero average value will be enhanced by the antenna gain and might for large antenna gains exceed the limits for allowed emitted intermodulation intensity.

Distributed multi-carrier amplifiers according to the present invention provide new possibilities of designing communication system antennas with stringent constraints on radiated intermodulation intensity. With a distributed multi-carrier power amplifier the linearization requirements on each module, or each amplifying means, are reduced as compared to the case in which a

central multi-carrier power amplifier is used. The lower linearity requirements will provide a higher efficiency in the multi-carrier power amplifying arrangement due to a lower back-off in the main amplifiers. As an example, for four carriers the usual 5-8% efficiency with 30dB C/I can be increased to about 15-20% if 20dB C/I is allowed instead.

In a particular implementation of the invention each of the signals output from the respective amplifying means, i.e. the amplified signals, are provided to (at least one) antenna element, which antenna elements are arranged to form an array antenna. The antenna elements may be arranged in a linear array or alternatively they may be arranged in a twodimensional array, usually planar.

As to the compensating control signal it is particularly a signal with an externally controlled phase, even more particularly, the externally controlled signal is provided to the error detecting means via a digitally controlled phase shifter. This is however not necessary and particularly the phase shifter does not have to be digitally controlled.

In one particular embodiment the entire arrangement may be realized as an RF-ASIC (Radio Frequency-Application Specific Integrated Circuit).

According to different implementations, in case a reference signal is used or even more particularly a pilot signal, such signal may be injected either before the main amplifier of each amplifying means or after the main amplifier of each amplifying means.

In a particular implementation the error detecting means includes a phase detector and an amplitude detector.

For an antenna in a matrix form the antenna elements are particularly arranged in  $m$  rows and  $n$  columns and for the antenna elements a number of amplifying means are arranged, e.g. in a similar manner. The signal output from an amplifying arrangement can be provided to one or more antenna elements.

The adding means particularly include  $n/m$  first adding means in which the output signals from the amplifying means are added in phase columnwise/rowwise and in a Butler matrix, here denoted a second Butler matrix for reasons as will be explained below, the sum signals from the  $m$  or  $n$  first adding means respectively are added. In such an embodiment a first switching means and a first Butler matrix are provided for selecting an input beam with one of a number of different phases, for each phase a number of amplifying means and antenna elements being provided. To the second Butler matrix as referred to above a second switching means is provided for selecting output beam. In a particular implementation of the embodiment as described above, means are provided for finding the minimum of the signal output from the second switching means. Said minimum is particularly found through using varying external control signals and the result is used to provide the compensating control signal which in turn is provided to each of the amplifying means as discussed earlier.

Therefore is also an array antenna provided which includes a number of antenna elements, to which antenna elements a number of amplifying means are provided, in which an input signal is amplified and provided to one or more antenna elements. Each of

the amplifying means include a main amplifier and means for linearizing the amplifying means respectively. Signal adding means are provided for adding the amplified signals output from the amplifying means in phase (coherently) and error detecting means are provided for detecting the average phase error (and amplitude error) of the amplified signals and for providing a compensating control signal. The compensating control signal is provided to each one of the amplifying means to control/minimize the average phase error of the amplified signals input to the antenna means.

10 In an advantageous implementation a pilot signal is input to each amplifying means which then is detected in the error detecting means to provide an estimation of the average phase error of the sum of the amplified signals. Particularly the signal level of the, or at least one, component originating from the pilot signal

15 output from the amplifying means is detected. The pilot signal may be (a) specific frequency component(s) or alternatively it can be a spread spectrum or CDMA- (Code Division Multiple Access) coded signal. In a particular implementation a signal with an externally controlled phase is provided to the error detecting means to

20 provide the compensating control signal. The antenna elements may be arranged in a linear array or in a twodimensional array. Amplifying means are arranged in m rows and n columns. At least as many antenna elements as amplifying means are provided, e.g. in a similar manner. For each column or for each row adding means are

25 provided in which the amplified signals are added vertically or horizontally. The resulting sum signals from either thereof are then added together in a Butler matrix. A switch is advantageously provided to select one of the beams output from the Butler matrix. Furthermore means are provided for finding the minimum of the

30 selected output beam using a varying external control signal. The resulting average value is used to control the amplifying means.

Therefore also a method is provided for controlling at least the average phase error of a multi-carrier power amplifying arrangement for an array antenna. The amplifying arrangement includes a number of amplifying means, each providing an amplified signal to at least one antenna element of the array antenna. The method includes the steps of: providing an input signal to each of the amplifying means, adding the amplified signals output from the respective amplifying means to generate a number of sum signals, detecting the average phase error of the sum signal(s), and using the detected average phase error to provide a compensating control signal. The compensating control signal is then provided to each amplifying means to control/minimize at least the average phase error. Advantageously is also the amplitude error compensated for. In a particular implementation the array antenna comprises a twodimensional array antenna and the output signals from the amplifying means are added in a number of adding means, one for each column, vertically, whereafter a Butler matrix is used in which the vertically added sum signals are added. A signal output from the Butler matrix is selected with switching means. All signals are added to find an average value, which is a scalar (real or complex) value.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The invention will in the following be further described, in a non-limiting way and with reference to the accompanying drawings, in which:

FIG. 1 shows a first embodiment of the invention with a number of amplifying means providing amplified signals to a number of antenna elements arranged in a linear array,

FIG. 2 is a second embodiment of an amplifying arrangement according the invention,

FIG. 3 is a simplified view of a linear array of antenna elements and amplifying means,

FIG. 4 is a simplified illustration of a feed-forward amplifier that can be used for linearization purposes,

FIG. 5 shows an example of an amplifying means of Fig. 2 more in detail,

FIG. 6 shows an example of an amplifying means,

FIG. 7 schematically illustrates an active multi-carrier power antenna comprising a 2 x 2 array of antenna elements, and

FIG. 8 is a schematically flow diagram illustrating controlling of the average phase error of a multi-carrier power amplifying arrangement for an array antenna.

#### DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows a first embodiment of the invention of a distributed multi-carrier amplifying arrangement 10 including four amplifying means 2A, 2B, 2C, 2D. Each amplifying means 2A, 2B, 2C, 2D includes a main amplifier 3A, 3B, 3C, 3D and via input means 1A, 1B, 1C, 1D input signals  $I_A$ ,  $I_B$ ,  $I_C$  and  $I_D$  are provided to the amplifying means 2A, 2B, 2C, 2D. Although each amplifying means includes linearizing means, these are not explicitly illustrated in this figure. As referred to earlier in the description the invention is not limited to any particular kind of linearizing

means. Each amplifying means in a distributed arrangement need not be as linear as a central multi-carrier power amplifier but the average phase and amplitude error has to be controlled to the same extent or with the same precision as in a central multi-carrier power amplifier. According to the invention it is possible to control the average performance of the distributed amplifying means by adding the signals output from all the amplifying means, or particularly amplifier modules, in phase and make a correction compensation in each one of the amplifying means. Thus, the amplified signals  $O_A$ ,  $O_B$ ,  $O_C$ ,  $O_D$  are input to signal adding means 5 thus providing a sum signal  $S_{10}$ . The adding of the signals is done coherently, i.e. the signals are added in phase. The sum signal  $S_{10}$  is then input to error detecting means 6 in which the phase error is detected. That can be done in different ways and using the result of the error detection a compensating control signal  $C_{10}$  is obtained. Particularly an external control signal  $C_1$  may be input to the error detecting means assisting in providing the compensating control signal  $C_{10}$ . This compensating control signal  $C_{10}$  is then input to each one of the amplifying means 2A, 2B, 2C, 2D. To remove the average phase error an external control reference phase in each one of the amplifying means is used to provide an external bias. One way of providing this is through adding a phase shifter which particularly may be digitally controlled for adding external control signal  $C_1$ . In that manner it is possible to make the phase detection believe that there is a phase error and compensate for it. As the same compensating signal is added to the amplifying means, the common average can be removed.

According to the present invention the IM signal in the boresight beam direction is not allowed to increase due to uncontrolled

average amplifier phase error. An additional advantage of adding the signals output from all the amplifying means before intermodulation detection or error detection, is that the signal level increases which makes it easier to get a good accuracy and to compensate for the inter-modulation products or the error. Thus, compensated output signals  $O_A$ ,  $O_B$ ,  $O_C$ ,  $O_D$  are obtained which are input to antenna elements 4A, 4B, 4C, 4D of a linear array antenna 4.

10 In Fig. 2 an alternative embodiment of a multi-carrier power amplifying arrangement 20 is illustrated. Like in Fig. 1 it comprises four amplifying means 2A', 2B', 2C', 2D', each with signal input means 1A', 1B', 1C', 1D' and signal output means. Also similar to the embodiment of Fig. 1 each amplifying means contains a main amplifier 3A', 3B', 3C', 3D'. Thus input signals  $I_A'$ ,  $I_B'$ ,  $I_C'$  and  $I_D'$  are amplified in the respective amplifying means forming amplified output signals  $O_A'$ ,  $O_B'$ ,  $O_C'$ ,  $O_D'$  which are provided to adding means 5' in which they are added in phase thus providing an output signal S20. The sum signal S20 is input to error detecting means 6'. In this embodiment, however, a reference signal, or here particularly a pilot signal  $P_1$  is input to each one of the amplifying means 2A', 2B', 2C', 2D' and in the error detecting means 6' a pilot signal detection is carried out, which here means that a frequency component of the pilot signal is detected. In an alternative embodiment the pilot signal may however be CDMA-coded. For error detecting the pilot signal can also be input to the error detecting means 6'. The pilot signal  $P_1$  is injected before or after the respective main amplifiers and it will show up in the coherent summation and will be detected in the error detecting means 6'. According to the invention the IM-signal in the boresight beam direction is not allowed to increase due to



uncontrolled average amplifier phase error as discussed above. Since there is only one input signal to the pilot detecting means 6' and one output signal from the error detecting means 6', the pilot detection will only have to perform a one-dimensional search to find the minimum pilot level. This can e.g. be done through varying the voltage which in turn controls the phase. A local minimum can then be found. Thus a compensating control signal  $C_{20}$  is provided which is input to all the amplifying means 2A', 2B', 2C', 2D' and in this manner compensated output signals are then input to the antenna elements 4A', 4B', 4C', 4D' constituting a linear array antenna 4'. Also in this case the linearizing means may be of any appropriate kind.

Although the number of antenna elements are illustrated as being the same as the number of amplifying means, this does not have to be the case. There may also be more antenna elements than amplifying means. For example might the outer amplifying means 2A', 2D' provide amplified signals to more antenna elements than 4A', 4D' which however not are shown. Of course also other alternatives are possible.

Fig. 3 schematically illustrates a linear array of antenna elements 4" to each of which an amplifying means is provided (there may be more antenna elements as discussed above), here indicated through amplifying arrangement 2". As in the preceding embodiments the output signals from the respective amplifying means are added in phase in adding means 5" thus providing a sum signal  $S_f$  which is input to pilot detecting means 6". (The pilot signal input to the respective amplifying means is however not illustrated in this Figure.) An externally controlled phase shifter (not shown) is used to provide a compensating control

signal  $C_{30}$  which is input to each of the amplifying means of the amplifying arrangement 2". The same compensating control signal  $C_{30}$  is added to all the amplifying means and the common average can be removed. Thus the IM-signal in the boresight beam direction is not allowed to increase due to uncontrolled average amplifier phase error. Since there is only one input signal and one output signal, the pilot detection will only have to perform a onedimensional search to find the minimum pilot level. It is also an advantage that all the signals output from the amplifying means are added before intermodulation detection since the signal level increases which in turn makes it easier to get a good accuracy and to compensate for it as discussed above.

Fig. 4 schematically illustrates an adaptive feed-forward amplifier including one example on linearizing means that can be used to achieve amplified signal linearity. Using this technique, two signal paths are used, one (the upper) that provides the power amplification and the other which is a copy or a reference of the original signal which is used to correct the non-linearities created in the first signal path. The phase shifters  $\Phi_0$  and  $\Phi_c$  and the attenuator  $A_c$  are controlled by additional circuitry not shown in Fig. 4. Also illustrated are a power divider and delay lines  $D_0$ ,  $D_1$ . Since the right loop of the circuit will decrease the non-linearities about 25-35dB, the remaining non-linear terms will, for an ensemble of amplifiers, have a random phase and amplitude. This feature can be used to avoid that non-linear terms are enhanced by the antenna gain resulting in an even spatial spread of intermodulation radiation. As referred to earlier, for any given temperature the control circuitry initially can be tuned to give zero average phase and amplitude error. However, as the conditions change, this will not be sufficient even if temperature

compensated circuits are used and for large antenna gains (e.g. planar arrays) the produced non-zero average value will be enhanced considerably by the array gain and exceed the limits for the allowed emitted intermodulation intensity. Presumably such radiation will be emitted at boresight since it can be suggested that the components have the same temperature dependence. However, the linearizing means as discussed above can be used in combination with the inventive concept to remove the average phase error.

Fig. 5 shows more in detail the amplifying means 2A' of Fig. 2. Like in Fig. 2  $I_A'$  illustrates the signal input to amplifying means 2A'. In power divider 201 the input signal  $I_A'$  is duplicated. One part of the input signal  $I_A'$ , i.e.  $I_{1A}$  is via amplitude control means 202 and phase control means 203 giving a signal  $I_{1x}$  which is provided to the main amplifier 3A' providing a signal  $I_{10x}$  which is provided to directional coupler and combiner 204 to which also a pilot signal P1 also is input. Amplitude and phase control means 202, 203 adjust the phase and amplitude of  $I_{1A}$  to provide an adjusted input signal  $I_{1x}$ . In dividing means 205  $I_{10x} + P1$  is duplicated (it contains the linearly distorted input signal and new frequency components caused by the non-linearity of the main amplifier 3A') and the signal is sent on to divider 206 from which the duplicated signals are sent to the comparison circuit 207; the signal is here denoted  $x + \varepsilon$  (meaning the input signal as amplified plus the pilot signal and the produced error ( $\varepsilon$ )) and to adding means 209 (the signal also here is  $x + \varepsilon$ ).

In comparing means 207 the signal is used to control phase and amplitude control means 203, 202. The second input signal  $I_{2A}$  is via delay means 208 sent to combining means 209. The adding means

209 may either consist of subtracting means so that a signal  $x + \varepsilon$  is reduced by the signal  $I_{2A}$ , also called  $x$ , thus providing the resulting signal  $\varepsilon$ . Alternatively means may be provided (not shown) to give the duplicated signals  $I_{1A}$  and  $I_{2A}$  opposite signs in which case  $I_{2A}$  is denoted  $\bar{x}$ . (This can also be provided for by power divider 201.) In that case the adding means 209a are adding means within the proper meaning of the term. In delay means 208 the input signal  $I_{2A}$  (or  $\bar{x}$ ) is delayed for a time period that equals the delay introduced in the opposite path, i.e. the path for input signal  $I_{1A}$ . In power splitting means 214  $\varepsilon$  is duplicated and one of the signals is provided to the comparison circuit 207 (as referred to above) whereas the other duplicated signal  $\varepsilon$  is provided to amplitude control means 215 and phase control means 216 thus providing an adjusted error signal which is input to error amplifier 217.

The other path of the signal resulting from combining means 204, i.e.  $I_{10x}P_1$ , is provided to delay means 210 and to directional coupling means 211 from which one of the duplicated signals is provided to combining means 218 in which a signal is combined with the adjusted error signal output from error amplifier 217. The signal output from combining means 218 is provided to a combiner 219 from which the output signal  $O_A'$  is obtained. The duplicated output signal from combiner 219 is provided to the comparison circuit 213.

The duplicated signal obtained from power divider 211 is input to phase control means 212 to which an external control signal  $C_{20}$  is input and the resulting signal is provided to the comparison circuit 213 in which it is compared with the signal  $O_A'$  to control

the amplitude control means 215 and the phase control means 216 acting on the error signal  $\varepsilon$  to be input to the error amplifier 217.

5 Although this was illustrated with reference to the amplifying means  $2A'$ , it should be clear that the same applies for the other amplifying means  $2B'$ ,  $2C'$ ,  $2D'$ .

10 It should however be clear that other kinds of linearizing means  $20A'$  also can be used and the inventive concept thus by no means relies on the use of any particular linearizing means.

Fig. 6 also shows the functioning for one amplifying means. In power splitting means 301 an input signal  $I_x$  is duplicated to take an upper path and a lower path. On the upper path  $I_x$  is provided to the main amplifier 304 thus providing an amplified signal  $I_x + \varepsilon$ , i.e. an amplified signal containing an error which in turn is duplicated in power splitting means 305 from where it is provided to delay means 310 and to combining means 309.

20 The input signal  $I_x$  is also sent along another path (the lower path as illustrated in Fig. 6) in which it is delayed in delay means 308. The delayed signal  $I_x$  output from delay means 308 is in combining means 309 combined with a signal  $I_x + \varepsilon$  output from power splitting means 305 from which it is subtracted, thus  
25 resulting in an error signal  $\varepsilon$  which is input to phase control means 316 and amplitude control means 315. The resulting signal is then provided to error amplification means 317 and the amplified error signal is in combining means 318 subtracted from the delayed  
30 signal  $I_x + \varepsilon$  resulting in an output signal  $O_x$  which is output to

antenna means. The signal is however also duplicated in power spitting means 319 providing an input to the phase shifter 312 to which an external control signal  $C_{60}$  is provided. From phase shifter 312 a signal is provided to the comparison circuit 313 which controls the error phase control means 316 and error amplitude control means 315. The thought with the external control signal  $C_{60}$  is to introduce a correcting signal. This is obtained after adding the output signals from all the amplifying means. This is so since it is not obvious that the phase/amplitude comparison circuit 313 is capable of detecting the phase error before the adding has taken place. After the adding, the relationship between signal and non-linear terms is potentially higher and thus the error is easier to detect.

In Fig. 7 an example of an implementation of the inventive concept on a 2 x 2 array antenna is disclosed. The functioning is the same for an  $k \times l$  array antenna wherein  $k$  and  $l$  are arbitrary integers.

The principle here is that the input signal  $I_z$  is added in the same beam direction as it is sent out. Therefore the signals output from amplifying means are first added vertically using an ordinary addition and then, with the use of a Butler matrix, the output signal is selected with the same switch control means that controls the input signal of the antenna (beam selection). All the signals are added to find a mean value (a scalar value). This means that the problem is reduced to a one-dimensional problem which can be solved comparatively easily.

Thus input signal  $I_z$  is provided to switch 401 in which a beam is selected via beam selection means 403. That means that one of two signals with one of two phases is obtained which is input to

Butler matrix 402. The signals that can be output from the Butler matrix 402 have different phase. Amplifying means 404A, 404B are arranged vertically and to each of them an antenna means 405A, 405B are provided; here, as referred to earlier in the application  
5 the number of antenna elements can exceed the number of amplifying means. Horizontally displaced in relation thereto amplifying means 404C, 404D are provided to which antenna means 405C, 405D are provided. In adding means 406, 407 the signals are added vertically thus, in this case providing two sum signals which are  
10 input to Butler matrix 408. Via a switch control 409 a beam is selected via beam selecting means 403. A signal output from switching means 409 is used to find the minimum, 410, as referred to above. C40 relates to an external control signal, as discussed with reference to the other embodiments, which is provided via  
15 phase shifter 411. In other aspects the functioning is the same as for the other described embodiments.

According to the invention a number of signals  $I_j$  are input to amplifying means  $A_j$  wherein  $j$  indicates the particular amplifying  
20 means, there being, in this case,  $n$  amplifying means, 101. A pilot signal  $p$  is also input to all the amplifying means, 102. Each amplifying means contains a main amplifier in which the input signals  $I_j$  are amplified, 103. This discuss more thoroughly earlier in the application, the amplified signals, here called  $A$   
25  $I_j$ , are linearized using the convenient linearizing means, 104. Then all the amplified signals  $A \times I_j$  are added in phase more coherently, in adding means resulting in a sum signal 1105. The sum signals  $I$  is then input to error detecting means, 106 in which components originating from the pilot signal is detected. The  
30 pilot signal may (as also referred to earlier in the application) relate to a specific frequency(frequencies), it may also be a so

called CDMA-coded signal, 107. Using the detected minimum value of the pilot signal for which an external control signal is used, a compensating control signal is created, 108. The compensating control signal is input to all amplifying means, 109.

5

According to the invention the errors are easier to detect since the detection is done after the signals have been added which is easier than if individual detectors are used for detection purposes since the signal amplitude is multiplied by the number of elements.

10

The invention is of course not limited to the illustrated embodiments but can be varied in a number of ways without departing from the scope of the claims.



## CLAIMS

1. A multi-carrier power amplifying arrangement (10;20;30;60;70) comprising a number of amplifying means (3A,3B,3C,3D; 3A',3B',3C',3D';2";404A-404D), each of which comprises signal input means (1A,1B,1C,1D;1A',1B',1C',1D'), signal output means, a main amplifier (2A,2B,2C,2D;2A',2B',2C',2D';304) and means (20A') for linearizing the amplifying means, characterized in that it further comprises signal adding means (5;5';5";406,407,408) for adding the output signals from the amplifying means in phase, error detecting means (6;6';6";207,213;313;410) for detecting the average phase error of the amplified signals and for providing a compensating control signal (C<sub>10</sub>;C<sub>20</sub>;C<sub>30</sub>;C<sub>60</sub>;C<sub>40</sub>) and in that said compensating control signal is provided to each amplifying means (3A,3B,3C,3D; 3A',3B',3C',3D';2";404A-404D) to at least compensate for the average phase error.
2. An arrangement according to claim 1, characterized in that a reference signal (C<sub>1</sub>;P<sub>1</sub>) is provided to each amplifying means (3A,3B,3C,3D;3A',3B',3C',3D';2") and in that said reference signal is used to detect the average phase error of the amplified signals.
3. An arrangement according to claim 2, characterized in that said reference signal consists of a pilot signal (P<sub>1</sub>) which is input to the amplifying means (3A',3B',3C',3D') and to the

error detecting means (6') and in that said detecting means (6') consists of means for detecting at least one component originating from the pilot signal, the result being used to provide the compensating control signal ( $C_{20}$ ).

5

4. An arrangement according to any one of the preceding claims, characterized in that an externally controlled control signal ( $C_1; P_1$ ) is provided to the error detecting means (6;6') to provide the compensating control signal.

10

5. An arrangement according to any one of the preceding claims, characterized in that the linearizing means consists of a feed forward loop for linearizing the amplified signal of the amplifying means.

15

6. An arrangement according to claim 5, characterized in that there is one feed forward loop for each amplifying means.

20

7. An arrangement according to any one of the preceding claims, characterized in that the signals output from the respective amplifying means are provided to at least one antenna element (4A,4B,4C,4D; 4A',4B',4C',4D';405A-405D), which antenna elements are arranged to form an array antenna (4;4';4").

25

8. An arrangement according to claim 7, characterized in that the antenna elements are arranged in a linear array (4;4';4").

30

9. An arrangement according to claim 7,  
c h a r a c t e r i z e d i n  
that the antenna elements are arranged in a twodimensional array  
5 (405A-405D).

10. An arrangement according to claim 4,  
c h a r a c t e r i z e d i n  
that the compensating control signal is a signal with an  
10 externally controlled phase.

11. An arrangement according to any one of the preceding claims,  
c h a r a c t e r i z e d i n  
that also the amplitude error is compensated for.  
15

12. An arrangement according to any one of the preceding claims,  
c h a r a c t e r i z e d i n  
that substantially the entire arrangement is realized as an RF-  
ASIC.  
20

13. An arrangement at least according to claim 2 or 3,  
c h a r a c t e r i z e d i n  
that the reference signal, particularly the pilot signal  $(C_1; P_1)$ ,  
is injected before the main amplifier of each amplifying means.  
25

14. An arrangement at least according to claim 2 or 3,  
c h a r a c t e r i z e d i n  
that the reference signal  $(C_1; P_1)$ , particularly the pilot signal,  
is injected after the main amplifier of each amplifying means.  
30

15. An arrangement according to any one of the preceding claims;

characterized in  
that the error detecting means (6;6';6") comprises a phase  
detector (216;316) and an amplitude detector (215;315).

- 5 16. An arrangement according to claim 10,  
characterized in  
that the externally controlled signal is provided to the error  
detecting means via a digitally controlled phase shifter.
- 10 17. An arrangement according to claim 7,  
characterized in  
that it includes  $n \times m$  amplifying means arranged in  $n$  rows and  $m$   
columns, and at least  $n \times m$  antenna elements.
- 15 18. An arrangement according to claim 17,  
characterized in  
that the adding means include  $m/n$  first adding means (406,407) in  
which the signals output from the amplifying means are added in  
phase columnwise/rowwise and a second Butler matrix (408) in which  
20 the added signals from the  $m/n$  first adding means respectively are  
added.
19. An arrangement according to claim 18,  
characterized in  
25 that a first switching means (401) and a first Butler matrix (402)  
are provided for selecting an input beam with one of a number of  
different phases, for each phase a number of amplifying means and  
antenna elements being provided.
- 30 20. An arrangement according to claim 18 or 19,  
characterized in

that to the second Butler matrix (408) a second switching means (409) is provided for selecting output beam.

21. An arrangement according to claim 20,

5 c h a r a c t e r i z e d i n

that means are provided for finding the minimum (410) of the signal output from the second switching means (409) and in that said minimum is found through using varying external control signal(s), the result being used to provide the compensating  
10 control signal.

22. An array antenna (4;4';4";405A-405D) including a number of antenna elements to which a number of amplifying means (3A,3B,3C,3D;3A',3B',3C',3D';2";404A-404D) are provided for  
15 amplification of input signals which then are provided to the antenna elements, each of said amplifying means including a main amplifier (2A,2B,2C,2D;2A',2B',2C',2D';304) and means (20A') for linearizing the amplifying means,

c h a r a c t e r i z e d i n

20 that signal adding means (5;5';5";406,407,408) are provided for adding the amplified signals output from the amplifying means in phase and error detecting means (6;6';6";207,213;313;410) for detecting at least the average phase error of the amplified signals and for providing a compensating control signal  
25 (C<sub>10</sub>;C<sub>20</sub>;C<sub>30</sub>;C<sub>60</sub>;C<sub>40</sub>), said compensating control signal being provided to each of said amplifying means to control/minimize the average phase error.

23. An array antenna according to claim 22,

30 c h a r a c t e r i z e d i n

that a pilot signal ( $P_1$ ) is input to each amplifying means and in that said pilot signal is detected in the error detecting means thus providing an estimation of the average phase error.

- 5 24. An array antenna according to claim 23,  
c h a r a c t e r i z e d i n  
that at least one component originating from the pilot signal  
output from the amplifying means is detected.
- 10 25. An array antenna according to any one of claims 22-24,  
c h a r a c t e r i z e d i n  
that an externally controlled signal is provided to the error  
detecting means to provide the compensating control signal.
- 15 26. An array antenna according to any one of claims 22-25,  
c h a r a c t e r i z e d i n  
that also the amplitude error is compensated for.
- 20 27. An array antenna according to any one of claims 21-24,  
c h a r a c t e r i z e d i n  
that the antenna elements are arranged in a linear array  
(4;4';4").
- 25 28. An array antenna according to claims 22-26,  
c h a r a c t e r i z e d i n  
that the antenna elements are arranged in a twodimensional array,  
that there are  $n \times m$  amplifying means in  $n$  rows and  $m$  columns  
and at least  $n \times m$  antenna elements.
- 30 29. An array antenna according to claim 28,  
c h a r a c t e r i z e d i n

that for each row or for each column of amplifying means adding means are provided in which the amplified signals in a row or a column are added and in that the resulting sum signals are added in a Butler matrix.

5

30. An array antenna according to claim 29,

c h a r a c t e r i z e d i n

that a switch (409) is provided to select one of the beams provided by the Butler matrix (408) and in that means (410) are provided for finding the minimum of the selected beam using a varying external control signal (C40), and in that the resulting average value is used to control the amplifying means.

10

31. Method of controlling the average phase error of a multi-carrier power amplifying arrangement for an array antenna, said amplifying arrangement including a number of amplifying means, c h a r a c t e r i z e d i n that it comprises the steps of:

15

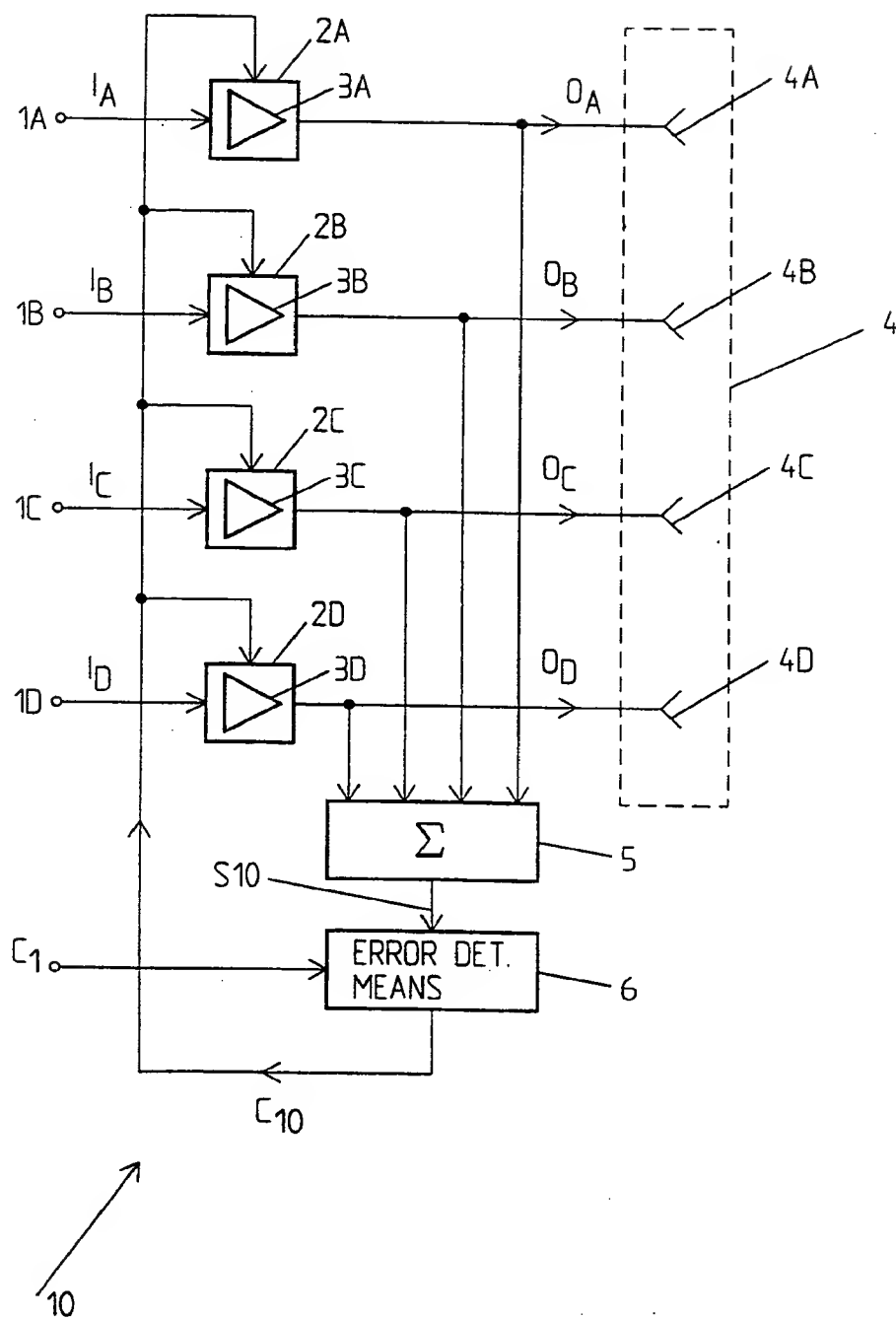
20

25

- providing an input signal to each of said amplifying means,
- adding the amplified signals output from the respective amplifying means to generate a number of sum signals,
- detecting at least the average phase error of the sum signal(s),
- using the detected average phase error to provide a compensating control signal,
- providing the compensating control signal to each amplifying means to control/minimize at least the average phase error.

Fig. 1

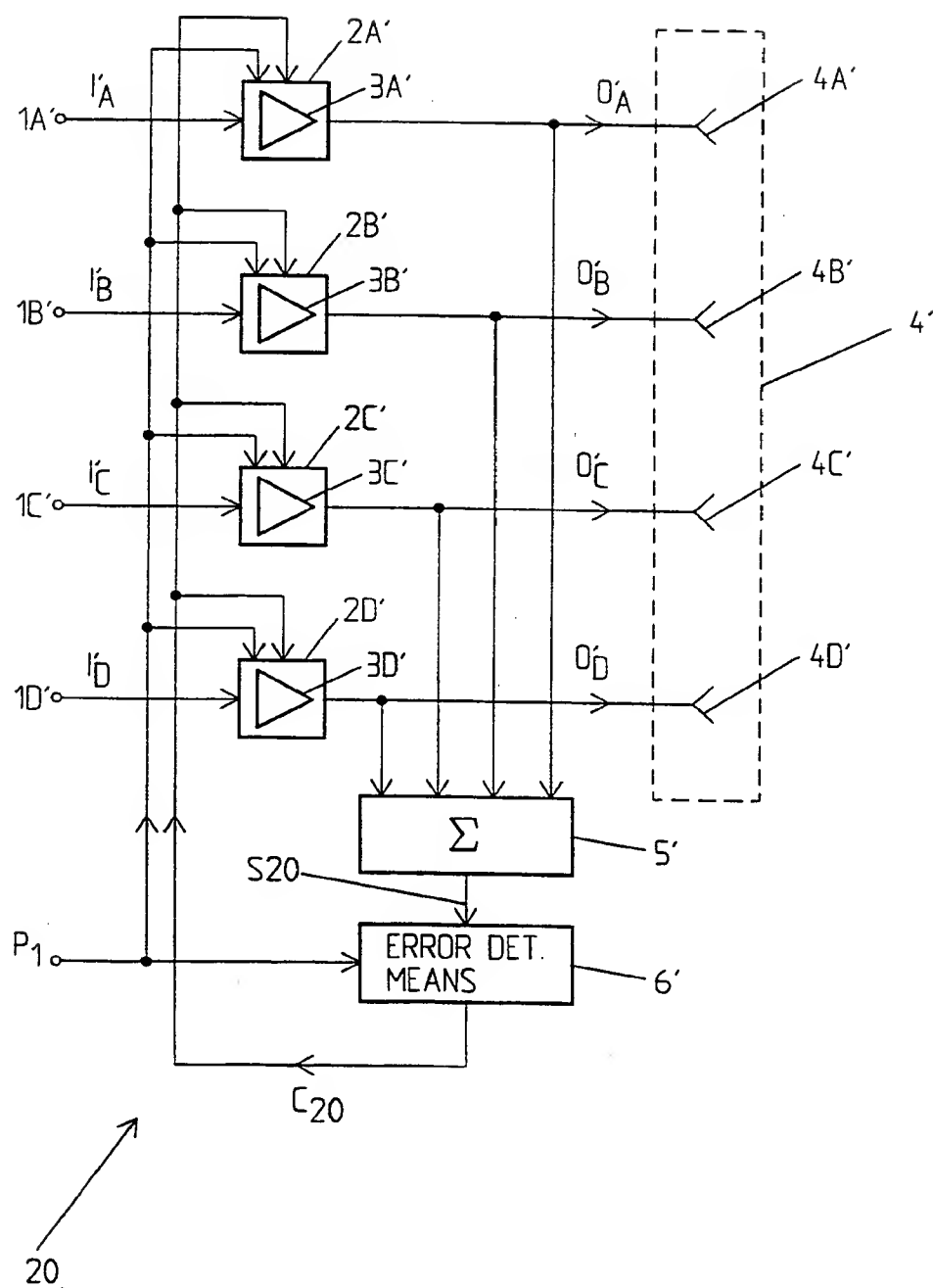
1/7





2/7

Fig. 2



3/7

Fig. 3

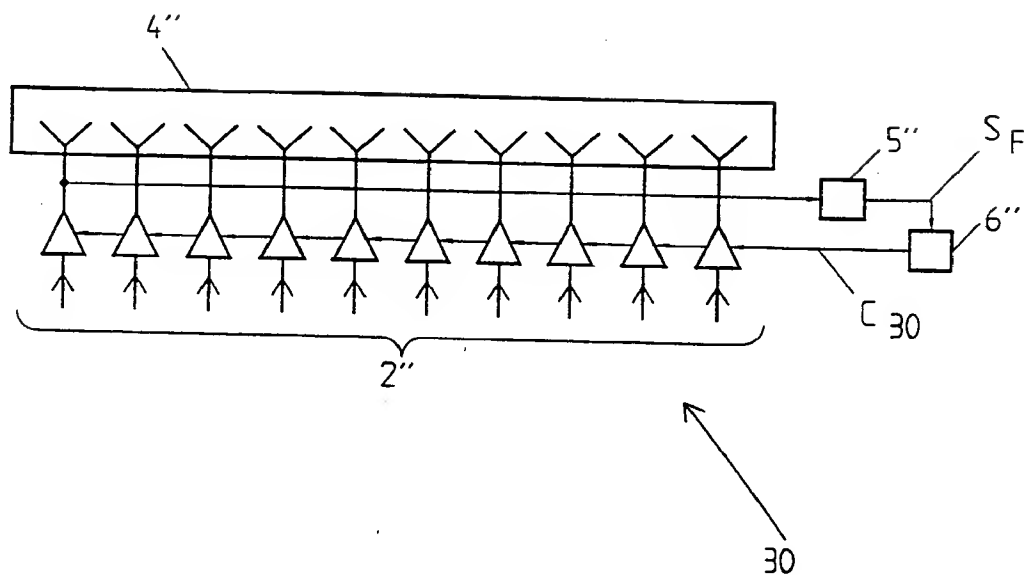
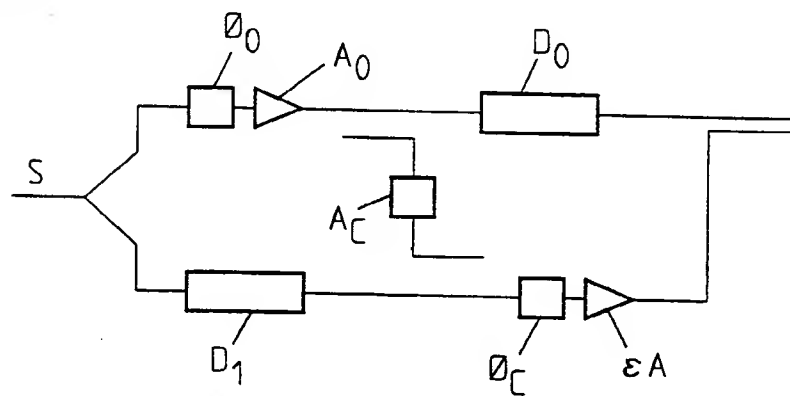


Fig. 4



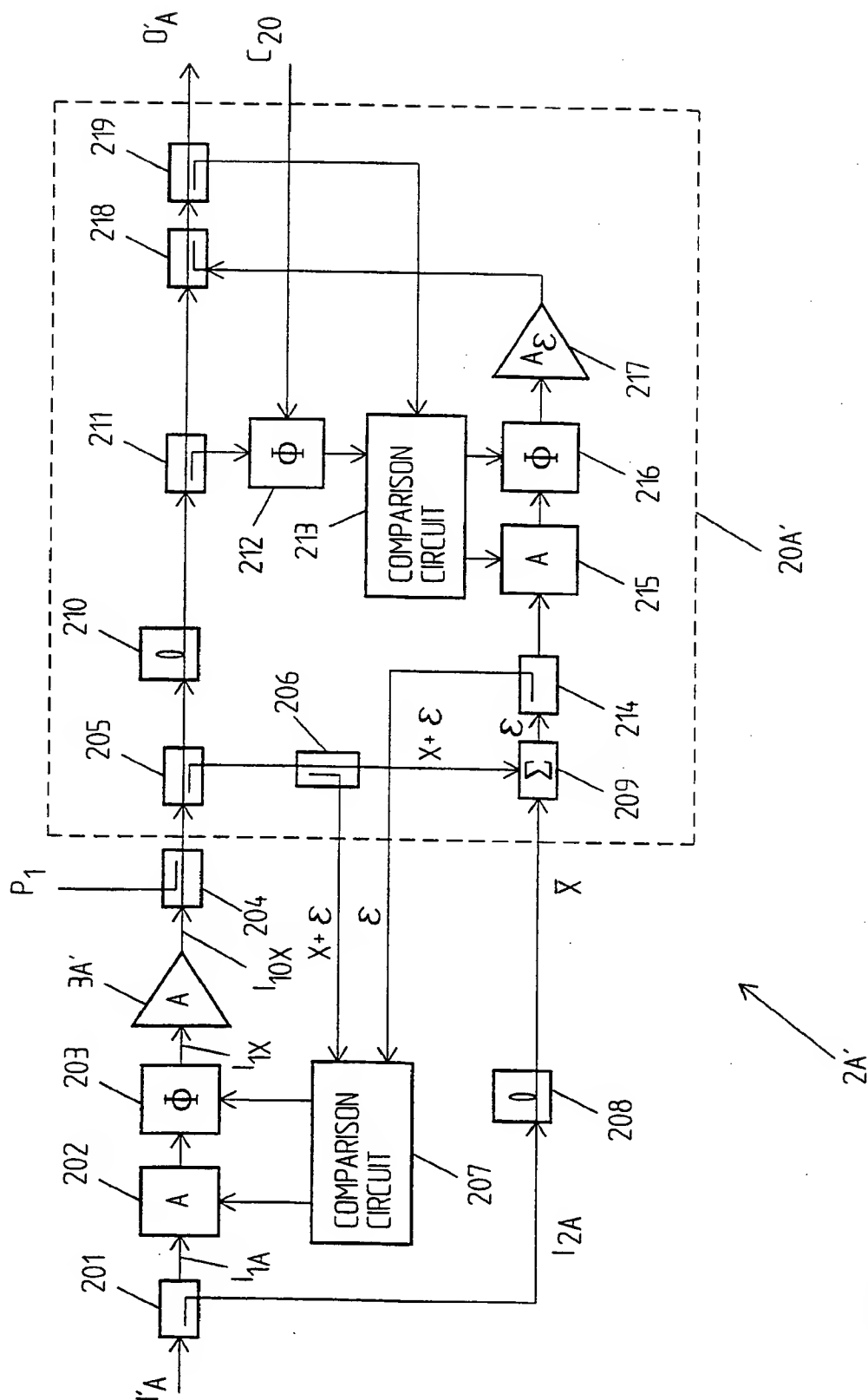


Fig. 5

5/7

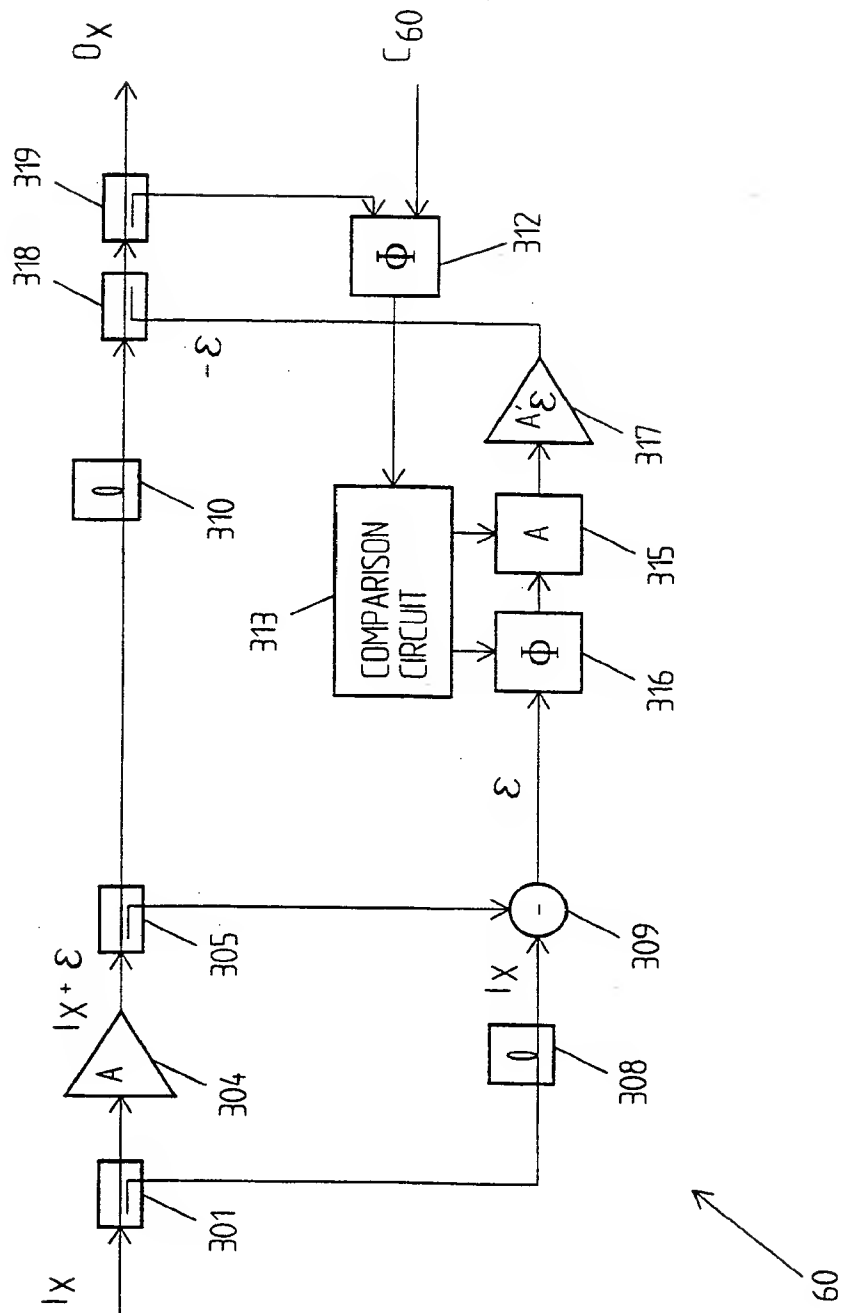


Fig. 6

6/7

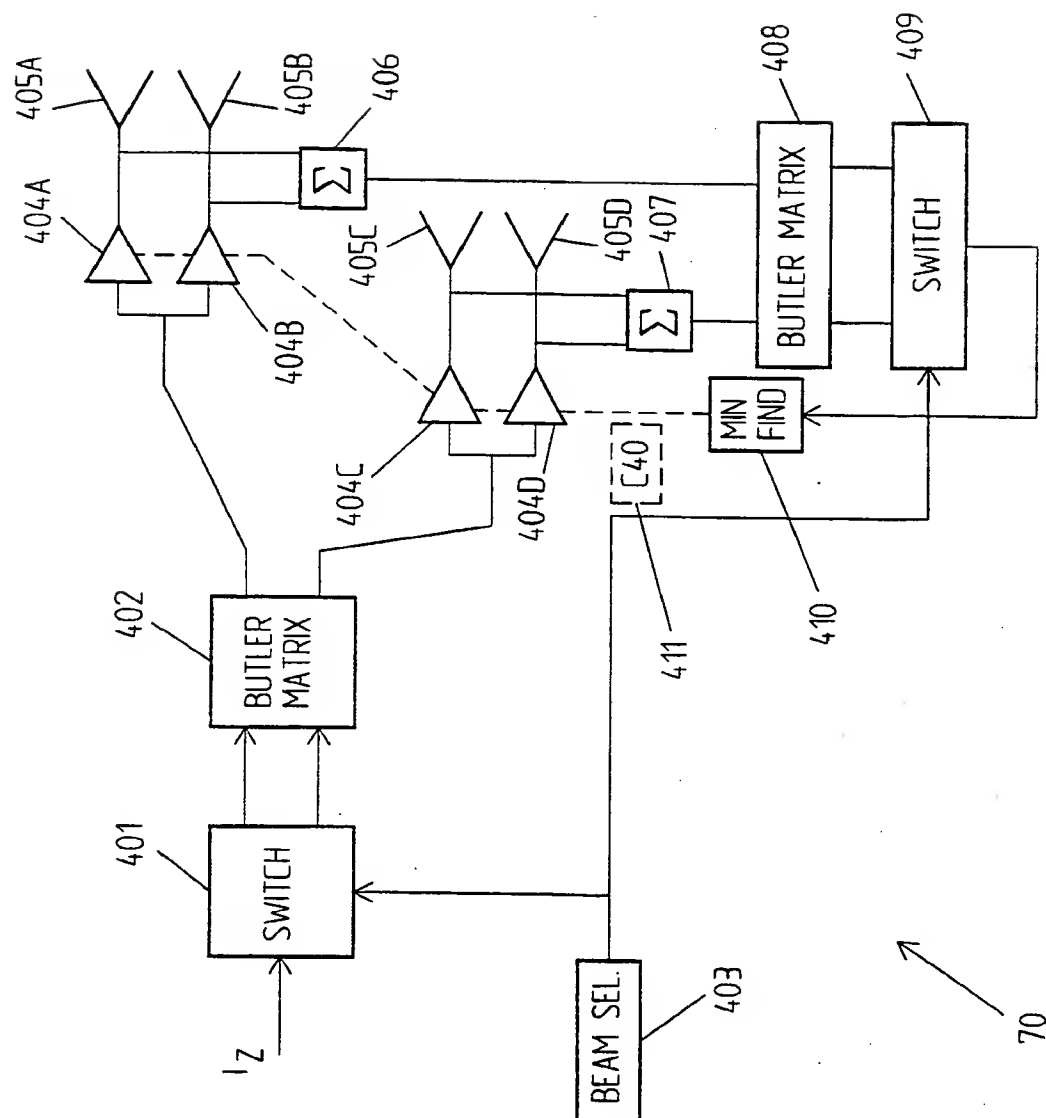


Fig. 7

7/7

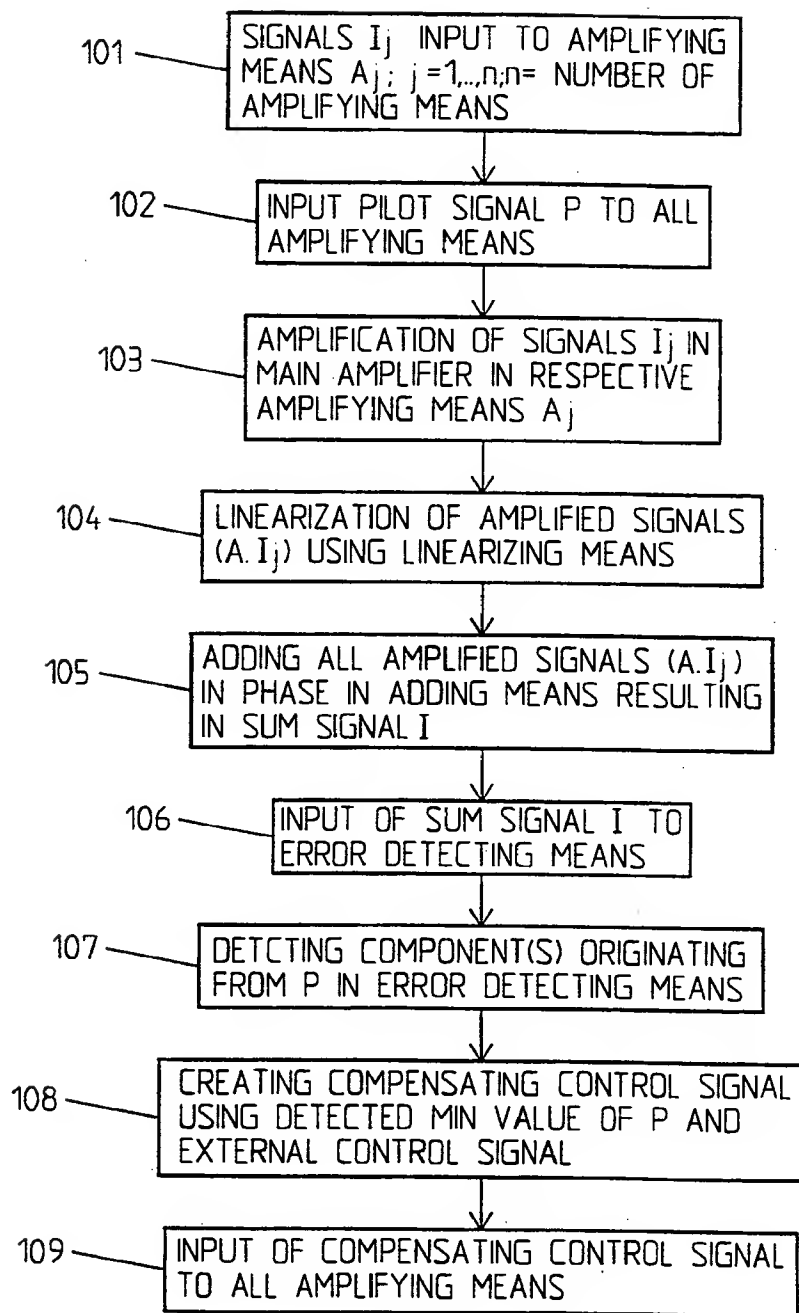


Fig. 8

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 99/01163

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>		
IPC6: H03F 3/21, H03G 3/20, H01Q 23/00 According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
Minimum documentation searched (classification system followed by classification symbols)		
IPC6: H03F, H03G, H01Q, H04B		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
SE,DK,FI,NO classes as above		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
JAPIO, WPI, INSPEC		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5604462 A (MICHAEL J. GANS ET AL), 18 February 1997 (18.02.97), figure 9 --	1,22,31
A	US 5561395 A (JOHN R. MELTON ET AL), 1 October 1996 (01.10.96), figure 2 --	1,22,31
A	EP 0768752 A1 (AT&T CORP.), 16 April 1997 (16.04.97), figure 7 --	1,22,31
A	US 5283587 A (EDWARD HIRSHFIELD ET AL), 1 February 1994 (01.02.94), figure 5 -- -----	1,22,31
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "I" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
22 November 1999		24-11-1999
Name and mailing address of the ISA: Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86		Authorized officer Bo Gustavsson/cs Telephone No. +46 8 782 25 000

# INTERNATIONAL SEARCH REPORT

Information on patent family members

02/11/99

International application No.

PCT/SE 99/01163

Patent document cited in search report			Publication date	Patent family member(s)		Publication date
US	5604462	A	18/02/97	NONE		
US	5561395	A	01/10/96	NONE		
EP	0768752	A1	16/04/97	JP 9135124 A		20/05/97
				US 5751250 A		12/05/98
US	5283587	A	01/02/94	CN 1038887 B		24/06/98
				CN 1095194 A		16/11/94
				DE 69323281 D		00/00/00
				EP 0600715 A,B		08/06/94
				IL 107783 A		31/03/96
				JP 6232621 A		19/08/94